

United States Senate

MEMORANDUM

Rec'd in OCA
31 July 1989

OCA 2642-89

Rudy

Attached are the materials that
I discussed with you on the
phone.

Wayne Auchin
224-1802

TO: Sen Glenn
Sen Bingaman
Sen Pell
OCA

United States Senate

WASHINGTON, DC 20510

001 912

July 20, 1989

The Honorable James A. Baker
Secretary of State
Department of State
Washington, D.C. 20520

Dear Jim:

On July 6, the Wall Street Journal reported that the German Aerospace Research Establishment, DLR may have aided the development of India's new intermediate range ballistic missile, the Agni. The official West German name for this organization is Deutsche Forschungsanstalt fur Luft- und Raumfahrt e.V. It is the largest research establishment for engineering sciences in the Federal Republic, and is financed primarily by public funds. It is the equivalent of our NASA.

The Journal's report cited allegations contained in the attached research report by the Wisconsin Project on Nuclear Arms Control entitled West German Aid to India's Rocket Program. According to this report, DLR has helped India develop guidance, heat shield and rocket engine technology, as well as manufacture rocket test facilities.

In light of the fact that DLR is involved in joint ventures with NASA and other U.S. entities, we believe these allegations should be investigated. This investigation should include an examination of the following issues:

1. the extent to which U.S. rocket technology, or satellite guidance technology has been or is being transferred to DLR or Messerschmidt-Boelkow-Blohm (MBB).
2. the extent to which DLR and/or MBB has been or is transferring such technology to India, Argentina, Iraq or other countries, possibly in violation of the Missile Technology Control Regime.

The Honorable James A. Baker
July 20, 1989
Page 2

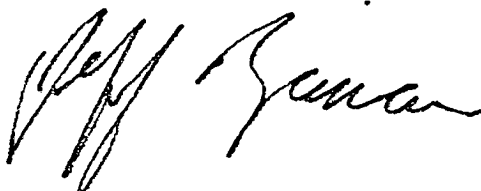
3. the extent to which NASA, DoD or other U.S. Government entities are cooperating with DLR and/or MBB on developing space technology and other technology subject to the Missile Technology Control Regime.

4. the relationship between DLR and Messerschmidt-Boelkow-Blohm (MBB).

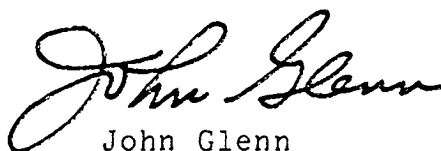
5. the extent to which U.S. Government contractors are cooperating with DLR and/or MBB on developing space technology and/or other technology subject to the Missile Technology Control Regime.

We are sure you agree with us that U.S. cooperation in space technology, defense technology or dual use technology should not extend to any firm that may be contributing to the spread of ballistic missiles. Please provide the results of your investigation into these issues by September 1, 1989. For your information, this request was also made of Secretary of Defense Cheney and NASA Administrator Truly.

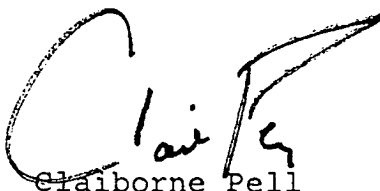
Sincerely,



Jeff Bingaman
United States Senator



John Glenn
United States Senator



Claiborne Pell
United States Senator

cc: The Honorable James A. Baker
The Honorable Richard B. Cheney
The Honorable Admiral Richard H. Truly

United States Senate

WASHINGTON, DC 20510

July 20, 1989

The Honorable Admiral Richard H. Truly
Administrator
National Aeronautics and
Space Administration
Washington, D.C. 20546

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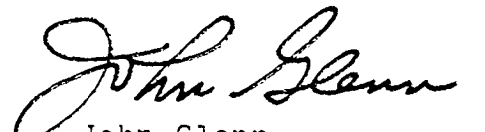
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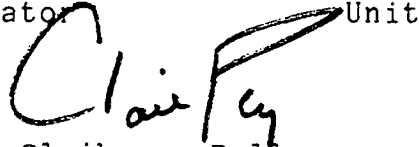
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United States Senate

WASHINGTON, DC 20510

July 20, 1989

The Honorable Richard B. Cheney
Secretary of Defense
Department of Defense
Washington, D.C. 20301-1000

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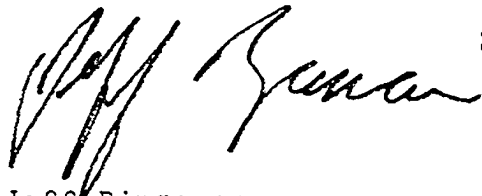
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United States Senator

cc: The Honorable James A. Baker
The Honorable Richard B. Cheney
The Honorable Admiral Richard H. Truly

Wisconsin Project on Nuclear Arms Control

Gary Milhollin

Professor, University of Wisconsin School of Law
Director

RESEARCH REPORT

WEST GERMAN AID TO INDIA'S ROCKET PROGRAM

July 7, 1989

Project office:
927 15th Street, N.W., Suite 1100
Washington, DC 20005 202-371-1121

India has just tested its first strategic missile, the "Agni" (meaning "fire"). The missile is reported to carry a one ton payload 1,500 miles--far enough to hit Chinese targets with nuclear warheads and change the strategic balance in Asia. If the missile works, West Germany, more than any other developed country, will be responsible.

Since the 1970s, German scientists have been helping India learn three indispensable missile technologies: guidance, rocket testing, and the use of composite materials. All three were supposed to be for India's space program, but all were equally useful for missiles. Altogether, India's rocket scientists have received an average of 80 man-months of German training per year.¹

Guidance

Germany has given India a tutorial in rocket guidance. In 1976, the German government's aerospace agency, DFVLR,² began helping India control the flight of sounding rockets. The first step was to put a German interferometer on an Indian rocket.³ An interferometer works by using antennas placed at different locations on the rocket to measure the phase of a radio signal received from the ground.⁴ The phase difference among the antennas reveals their relative position on the rocket and thus the rocket's attitude. The system allows a ground station to

monitor and correct the attitude, and infer from it the rocket's position, which can be used to decide when to fire a stage. The first launch was in 1978, and by 1981 the project was totally successful and had been expanded to include an on-board DFVLR microprocessor.⁵ By April of 1982, India had tested an Indian-made version of the same interferometer.⁶

The next step was to make a system that did not depend on signals from the ground. India produced a study for doing so in July 1981.⁷ India would supply the rockets and satellites and Germany would provide the brains of the guidance system.⁸ The key would be an on-board computer using a microprocessor (i.e., computer chip) based upon the Motorola family M 68000.⁹ Germany would supply the microprocessor and the software to run it.¹⁰ The system, called the "autonomous payload control system," would provide "full autonomous navigation capability to spaceborne sensors."¹¹ It would determine "position, velocity, attitude, and precision time in a real-time mode."¹²

In effect, this was a plan to develop an inertial navigation system, one that could guide a payload through space by determining its position and speed at any moment. Unfortunately, any navigation system capable of doing that can also determine the position and speed of any other payload launched by a rocket, such as a warhead. And if one can determine a warhead's speed and position in space, one can guide it to its target.

The plan was carried out. By January 1982, Germany and India had agreed on joint projects for the Autonomous Payload Control Rocket Experiment (APC-Rex),¹³ the program that would carry the plan forward. At the same time, India announced that it would also design a new navigation system for its space launchers. India wanted to replace the "open loop" guidance system used on its first launcher, the SLV-3 (Space Launch Vehicle-3), with a "closed loop" system for its ASLV (Advanced Space Launch Vehicle) and its PSLV (Polar Space Launch Vehicle). An open loop system can only correct the rocket's attitude; it cannot correct deviations from the planned flight path. A closed loop system can correct both attitude and deviations because it senses and determines the rocket's position in space; it amounts to an autonomous navigation system.¹⁴

But India would need a brain for the new closed loop system. To provide it, India announced that it would develop the "Mark-II" on-board processor, "based on [the] Motorola 6800 microprocessor with 16-bit word length" [sic--according to Motorola, the 16 bit Motorola is the M 68000].¹⁵

Thus, at the time India began to use the German microprocessor and its software for the APC-Rex program, it began to use the same processor for its new space launchers. The timing of subsequent events shows that it continued to do so.

In 1982-83, shortly after India received the processor, India's PSLV/ASLV program announced that "an engineering model of the...Mark-II based on the Motorola 6800 [sic] microprocessor has been integrated and exhaustive tests are being carried out."¹⁶ In 1983-84, when the APC-Rex program was reporting that "as part of the...DFVLR collaborative program...development of an onboard computer for autonomous payload control is in progress,"¹⁷ the PSLV/ASLV program was reporting that "design review was conducted on inertial navigation systems with the participation of international experts."¹⁸ In 1984-85, when the APC-Rex program was reporting that "design of the on-board [guidance] packages was completed,"¹⁹ the PSLV/ASLV program reported that "design of on-board processors for PSLV based on 16-bit microprocessors has been completed."²⁰ And in 1986-87, when the APC-Rex program was reporting that "development and validation of hardware and software packages for APC-Rex are in their final stages,"²¹ the PSLV/ASLV program was reporting that "bread board models of on-board computers based on microprocessors have been realized."²²

In 1988, India announced that "the development of hardware and software for APC-Rex has been completed...the flight model is being assembled."²³ This was at the same time that India was assembling the Agni missile. According to Indian press reports, the Agni was completed at the beginning of 1988²⁴ and has been ready to test since July of 1988.²⁵ In January of 1989, Agence France Press cited Indian scientists as saying that the Agni uses

a "twin microprocessor-based missile guidance system...."²⁶ The guidance system is also said to have "interrupt driven real time software."²⁷

In May 1989, a DFVLR official said that "the APC-Rex program has not yet been concluded, but it will come to an end in 1989."²⁸ This suggests that the German-Indian guidance effort has continued despite India's launching of the Agni missile. Moreover, it suggests that DFVLR's more recent contributions to the program may have violated the Missile Technology Control Regime, formally adopted by West Germany in April 1987.²⁹

So the German-Indian guidance loop seems to have closed. In 1987, when the Indians assembled the Agni, they had studied and developed only one brain for a rocket guidance system: the German system based on the Motorola microprocessor and its software. Over a decade, Germany's guidance tutorial helped India build and test a navigation package based on that system. Did India put that system in the Agni, or did India invent some other system, not mentioned in any Indian space program report, completely from scratch? If India did invent some other system from scratch, did the Indian rocket scientists block out of their minds the lessons of the decade-old German guidance tutorial? The evidence is very strong that when the Agni flies, it will owe its brain to German engineering.

Rockets

Wind tunnel tests are essential to study the aerodynamics of any rocket; they were essential for the first stage of the SLV-3, India's first space launcher. In 1974-75, DFVLR tested a model of the first stage of the SLV-3 at the DFVLR wind tunnel at Cologne-Portz.³⁰ Unfortunately, the first stage of the SLV-3 appears to be the first stage of the Agni missile.

The first mention of the "Agni" rocket is as a booster for the PSLV.³¹ In 1982-83, 72 Agni motors were used to test the imported solid propellant fuel to be used in boosters for the PSLV program.³² The PSLV is slated to have six identical boosters for its first stage, and these boosters, in turn, will either be identical to or derived from the first stage of the SLV-3.³³ So it appears that the "Agni" missile will be the first stage of the SLV-3, or a version of it. This conclusion is supported by the statement by Agence France Press that the Agni missile will use a solid propellant first stage "similar to" the first stage of the SLV-3. Thus, the "Agni" missile's first stage owes its development to German testing. And the Indian missile program, despite what India says, owes its rockets to the Indian space program.

DFVLR also helped India build high altitude rocket test facilities. DFVLR trained Indian engineers in high altitude

testing and furnished a complete facility design.³⁴ India will use, and may already have used, this technology to test the liquid fueled apogee motor for the INSAT-II TS, and the liquid fueled upper stage of the PSLV.³⁵ India may also have used it to test the second stage of the Agni missile, which is reported to be liquid fuelled,³⁶ and must have been tested somewhere.

Materials

Strong, lightweight "composite" materials are used to make rocket nozzles and nosecones.³⁷ In the mid-1970s, DFVLR began to give Indian scientists "on-the-job training" in composites at its institutes in Stuttgart and Braunschweig. The subjects ranged from "glass fibre reinforced plastics via impregnated materials to carbon fibre reinforced composites."³⁸ In June of 1988, the United States indicted two Egyptian military officers for trying to smuggle carbon fiber composites out of the United States.³⁹ Export of the composites was strictly controlled; they were being used for rocket nozzles and the nose cones of the MX, Trident, and Minuteman nuclear missiles.⁴⁰

The German training was intended to allow India to make rocket nozzles and nose cones of its own, which could be for either missiles or space launchers. The Indians learned "composition, manufacturing processes, quality control, and error detection."⁴¹

To help the Indians use the composites, DFVLR gave India the documentation for a precision filament winding machine, which would enable India to wind the filaments into rocket engine nozzles and housings.⁴² India built the machine and commissioned it in 1985-86.⁴³

APPENDIX

FRG ROCKET AND MISSILE TECHNOLOGY TRANSFERS TO INDIA

Company	Date	Technology
DFVLR	1973	Trained Indian scientists to perform high altitude simulation tests of rocket motors. ⁴⁴ Provided a complete design of high altitude rocket test facilities. ⁴⁵
DFVLR	1973	Helped construct test facilities for India's new high-thrust liquid rocket motor, the Vikas, ⁴⁶ an Indian-produced version of France's Viking rocket motor. ⁴⁷ India plans to use the Vikas as the second stage of its Polar Satellite Launch Vehicle, ⁴⁸ which will be capable of placing a 2,200lb payload into a 562mi orbit. ⁴⁹
DFVLR	1973-1974	Arranged delivery, by German companies, of electronics and other equipment to the Indian Space Research Organization's laboratories to improve measurement and calibration capabilities. ⁵⁰
DFVLR	1974-1975	Conducted wind tunnel tests in Germany of the SLV-3 rocket, ⁵¹ which, converted to a missile, could deliver a 1,000lb warhead 1,900mi. ⁵²

Company	Date	Technology
DFVLR	1977	Provided documentation for a precision filament winding machine used to make rocket engine nozzles and housings. ⁵³
DFVLR	1981	Participated in the design review of India's hypersonic wind tunnel and heat transfer facilities used to test rockets. ⁵⁴
DFVLR	1973- 1982	Provided "on-the-job" training in the manufacture and use of glass and carbon fiber reinforced composite materials ⁵⁵ used to make rocket engine housings, engine nozzles and nose cones.
DFVLR	1973- 1982	Provided DFVLR developed software for satellite orbital analysis, orbital positioning and attitude control, and helped India modify this software for Indian computers. ⁵⁶
DFVLR	1976- 1982	Co-developed and tested a radio frequency interferometer ⁵⁷ for rocket guidance. ⁵⁸
Krupp	1983- 1984	Provided rocket motor segment rings. ⁵⁹
DFVLR	1976- present	Co-developed and tested computers for rocket payload guidance based on U.S. microprocessors, ⁶⁰ useful for ballistic missile guidance.

Notes

1. Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (German Aerospace Research Establishment), DFVLR/ISRO-Colloquium about a Decade of Cooperation in the Field of Space Research and Technology, on January 27th, 1982, in Bangalore, India, DFVLR-Mitt. 83-03., at p. 20. Hereinafter cited as DFVLR Colloquium. ISRO is an acronym for the Indian Space Research Organization.

2. Id., at p. 12. The DFVLR is a "research organization ... mainly funded by the German Federal Government. It has about 3,200 employees...[and] covers the following research fields: flight mechanics, guidance and control, fluid mechanics, materials and structures, energetics and propulsion systems, communications and remote sensing." Id. In March 1989, the DFVLR announced that it has simplified its name and abbreviation to the Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V., or DLR. The English translation remains the German Aerospace Research Establishment, however. DFVLR, DFVLR Simplifies: Now Its DLR (Press Release, Washington Office), March 29, 1989. For a more recent description of the DLR, see DLR, Annual Report 1987, Highlights (DLR Washington Office), February 1989, p. 1. This report states: "DLR, the German Aerospace Research Establishment, is the largest research establishment dealing with engineering sciences in the Federal Republic of Germany. It has more than 4000 employees. Its research centers are located in Braunschweig, Göttingen, Köln-Porz (Cologne), Oberpfaffenhofen (near Munich), and Stuttgart, with branches in Hamburg, Berlin, Trauen, Bonn, Lampoldshausen and Weilheim. DLR is financed primarily by public funds." It adds: "DLR's scientific-technical competence arises from its five scientific research departments (Flight Mechanics/Guidance and Control; Fluid Mechanics; Materials and Structures; Telecommunications Technology and Remote Sensing; Energetics)..."

3. DFVLR Colloquium, id., at pp. 26-27.

4. See, e.g., G. Mayer and G.E. Todd, "An Attitude Sensing Technique for Earth Resources Survey Rockets, Using RF Interferometry," Journal of the British Interplanetary Society, Vol. 28, pp. 673-680, 1975.

5. DFVLR Colloquium, note 1 above, at p. 27.

6. Government of India, Department of Space, 1982-83 Annual Report, p. 17.

7. DFVLR Colloquium, note 1 above, at pp. 93-94.

8. Id.
9. Id.
10. Id.
11. Id., at p. 94.
12. Id.
13. Government of India, Department of Space, 1981-82 Annual Report, at p. 42.
14. For descriptions of open and closed loop guidance systems on Indian rockets see U.S. Department of State, Cable New Delhi No. 31294, para. 53-57, December, 1987.
15. Government of India, Department of Space, 1981-82 Annual Report, pp. 21-22.
16. Government of India, Department of Space, 1982-83 Annual Report, p. 21.
17. Government of India, Department of Space, 1983-84 Annual Report, p. 25.
18. Id., at pp. 29-30.
19. Government of India, Department of Space, 1984-85 Annual Report, p. 30.
20. Id., at p. 29-30.
21. Government of India, Department of Space, 1986-87 Annual Report, p. 45.
22. Id., p. 45.
23. Government of India, Department of Space, 1987-88 Annual Report, p. 48.
24. The Hindu (New Delhi), Jan. 24, 1989.
25. The Hindu (Madras), July 14, 1988, p. 7, reproduced in JPRS-NEA-88-065, Sept. 6, 1988, p. 39.
26. Pratap Chakravarty, "Test of New Surface-to-Surface Missile Planned," Agence France Press (Hong Kong), Jan 9, 1989, reproduced in JPRS-TND-89-001, Jan. 13, 1989, p. 18.
27. The Hindu (Madras), July 14, 1988, p. 7, reproduced in JPRS-NEA-88-065, Sept. 6, 1988, p. 39.

28. Letter from Dietmar Wurzel, head of DFVLR's Washington, DC Office, to Gary Milhollin, May 1, 1989.
29. For more information on the Missile Technology Control Regime, see John Goshko, "7 Nations Bar Sales of Missiles," Washington Post, April 17, 1987 and U.S. Department of Defense, Missile Technology Control Regime: Fact Sheet to Accompany Public Announcement, April 16, 1987.
30. DFVLR Colloquium, note 1 above, at p. 22.
31. Government of India, Department of Space, 1982-83 Annual Report, p. 21.
32. Id.
33. "India--The Way Forward," Spaceflight, Dec., 1986, p. 434.
34. DFVLR Colloquium, note 1 above, at p. 25.
35. Government of India, Department of Space, 1987-88 Annual Report, p. 53.
36. Chakravarty, note 26 above.
37. See, e.g., U.S. Department of Justice, United States Attorney for the Eastern District of California, Press Release, June 24, 1988.
38. DFVLR Colloquium, note 1 above, at p. 24.
39. Philip Shenon, "U.S. Accuses 2 Egyptian Colonels In Plot to Smuggle Missile Material," New York Times, June 25, 1988, p. 1; Ruth Marcus and David B. Ottaway, "Egyptian Officer Tied to Smuggling Effort," Washington Post, June 25, 1988, p. 1.
40. Shenon, id.
41. DFVLR Colloquium, note 1 above, at p. 24.
42. Id., at p. 22.
43. Government of India, Department of Space, 1985-86 Annual Report, p. 40.
44. DFVLR Colloquium, note 1 above, at p. 20. See also DFVLR, Annual Report 1974, p. XXXIV.
45. DFVLR Colloquium, id., at p. 25. According to this report, a team of Indian scientists and engineers completed a one year program at DFVLR in Lampoldshausen in the middle of 1973. The report states:

"The program consisted of a completed design of test facilities for rocket propulsion systems under high altitude conditions, a field of DFVLR expertise. In the following years, questions of technical engineering, instrumentation, and control technology were solved during on-the-job training periods with [ISRO] staff members in Lampoldshausen and through direct consultation by DFVLR specialists at ISRO. As a result of this cooperation, the HAT-2 (High Altitude Test) facility [in India] started operations in 1980.... Presently, the adaptation of HAT-2 is being discussed with regard to the increased requirements for the upper stages of the advanced PSLV launcher, as well as to the tests of apogee liquid motors. DFVLR is prepared to assist with technical advice."

For more details on the Indian High Altitude Test Facility (HAT-2), see Government of India, Department of Space, 1979-80 Annual Report, p. 23. In 1979-80, according to this report, the facility was:

"in the final stages of commissioning...[t]he milestones crossed by this project so far include the installation of the vacuum chamber, diffuser eject system, cooling system, steam generation and pressurization system, and the commissioning of the programmable logic control and instrumentation systems."

In 1980, the HAT facility was commissioned "with the successful firing of Apple ABM motor in April." Government of India, Department of Space, 1980-81 Annual Report, p. 28. In 1987-88, India built separate HAT facilities for testing the INSAT-II TS Liquid Apogee Motor engine testing and the liquid upper stages of the PSLV. Government of India, Department of Space, 1987-88 Annual Report, p. 53.

46. DFVLR Colloquium, Id. India also "[desired] the option to test some of the Vikas engines at DFVLR test facilities." The report does not state whether DFVLR tested the engines.

47. Government of India, Department of Space, 1977-78 Annual Report, p. 44; Government of India, Department of Space, 1978-79 Annual Report, p. 21; and David Velupillai, "ISRO: India's Ambitious Space Agency," Flight International, June 28, 1980, p. 1468. The 1977/78 report states:

"Through an agreement with the French firm, Societe Europeene de Propulsion (SEP), ISRO [Indian Space Research Organization] engineers have been participating in the Viking rocket engine development programme of the European launch vehicle, 'Ariane'. By this means, the technology and know-how are being acquired for the development and testing of high-thrust liquid rocket motors."

The 1978/79 report gives more detail on the extent of France's transfer of the Viking technology: "Most of the documents and drawings on system description, specifications, fabrication, testing and analysis have been received." According to the

report in Flight International, the Vikas is "built under license from Societe Europeene de Propulsion (SEP)."

48. Velupillai, id. Velupillai states that the "Second-stage [of the PSLV] is likely to be one of the Viking engines used on Europe's Ariane, built under license" by India from SEP.

49. Government of India, Department of Space, 1987-88 Annual Report, p. 40.

50. DFVLR Colloquium, note 1 above, p. 20; DFVLR, Annual Report 1974, p. XXXV. The DFVLR annual report states:
 "In cooperation with the Federal Ministry for Research and Technology, the ISRO had been offered scientific instruments for use in its centers in Trivandrum and Ahmedabad from funds available during the business year. On the basis of a list of instruments put together by ISRO at the end of October for a total value of approximately 60,000 Marks, German firms were requested to bid. After an examination of these offers and of corresponding technical documentation, and after the exact shipment date of all instruments via the ISRO was set, the coordinator placed the first order in the middle of December 1974."

51. DFVLR Colloquium, id., at p. 22. See also DFVLR, Annual Report 1974, p. XXXIV. The Annual Report 1974 states:
 "Upon request of the ISRO, the Institute for Applied Gas Dynamics of the DFVLR took on the task of carrying out wind tunnel measurements on models of an Indian rocket. The research program was started on November 1, 1974 with measurements on a model (1:25) in the hypersound tunnel (force and pressure measurements) which were nearly complete by the end of the year. The measurements for two additional program parts (stage separation and dynamic stability) supposedly are to be finished in the spring of 1975."

52. Computations performed by author.

53. DFVLR Colloquium, note 1 above, at p. 22. The DFVLR report states: "Documentation, concerning a precision winding machine developed by DFVLR, is placed at ISRO's disposal for the REPLACE [Reinforced Plastics Center] project." According to a recent ISRO annual report, "a special purpose winder for nozzle components fabrication was built and commissioned" at the ISRO Reinforced Plastics Center [REPLACE] in India during 1985-86. Government of India, Department of Space, 1985-86 Annual Report, p. 40.

54. DFVLR Colloquium, id., at pp. 25-26; Government of India, Department of Space, 1980-81 Annual Report, p. 45. The Indian report states that "DFVLR specialists participated in an ISRO Workshop in February 1981 to discuss the commissioning and

utilization of ISRO's Hypersonic Wind Tunnel and Heat Transfer Facilities." The DFVLR report states that "in March 1981, two DFVLR scientists visited Trivandrum [in India] to participate in the design review of the VSSC hypersonic and heat transfer facilities, as well as in the corresponding workshop."

55. DFVLR Colloquium, id., at p. 24. The report states: "Since the beginning of cooperation [in 1973], attention has been paid continuously to the area of materials and structures. ISRO's interest was exclusively directed to composite materials. In this field, DFVLR was able to offer on-the-job trainings in its institutes in Stuttgart and, later on, in Braunschweig. The interest ranged from glass fibre reinforced plastics via impregnated materials to carbon fibre reinforced composites. Composition, manufacturing processes, quality control, and error detection (among other non-destructive tests) were emphasized in the common studies. Composites of carbon fibre reinforced plastics were the subject of on-the-job trainings in DFVLR, university institutes, and the German space industry. These plastics are particularly important for ... rocket engines (nozzles) due to their low weight and material stability."

56. Id., at p. 26; Government of India, Department of Space, 1979-80 Annual Report, p. 41. The DFVLR report states: "Software developed at DFVLR for satellite orbits, positioning and attitude control have been adapted by Indian scientists for their own computers. Lately, in joint efforts, these software packages were modified to increase the performance." The Indian report states: "Training of Indian scientists at various agencies of DFVLR and West German universities continued. A few short-term courses relating to computer software for vehicle tracking, orbital analysis and control were conducted by DFVLR scientists for the benefit of Indian scientists and engineers."

57. DFVLR Colloquium, id., at p. 27; Government of India, Department of Space, 1977-78 Annual Report, p. 73. The DFVLR report states, "[ISRO sent] some members to Oberpfaffenhofen for participation in the construction of the interferometer and in the preparation for rocket payload integration." In addition, DFVLR interferometers were tested in 1978 and 1979 on Indian sounding rockets, and in 1979, a modified version of the DFVLR interferometer was tested in India on an Indian sounding rocket. DFVLR Colloquium, id. The Indian report states: "DFVLR and ISRO are collaborating on some scientific and technological experiments of importance to both agencies. These include testing of rocket-based attitude sensor payloads and calibration of the ISRO interferometer system."

58. Personal communication with U.S. Department of Defense official; Douglas M. Considine, ed., Van Nostrand's Scientific

Encyclopedia (Van Nostrand Reinhold, 1988), p. 1580. According to the U.S. official, the Soviet Union used interferometers to guide some of its first ballistic missiles. Van Nostrand's states: "In space technology, interferometers are applied to measurements in radio (and radar) systems. They include space vehicle guidance systems in which target direction is determined by comparing the phases of echo signals as received by two precisely spaced antennas on the spacecraft."

59. Government of India, Department of Space, 1983-84 Annual Report, p. 21. "Out of two segment rings rolled at Messrs. Krupps, West Germany, ... one has been delivered..."

60. DFVLR Colloquium, note 1 above, at p. 93. "The objective of German involvement [in the ISRO/DFVLR autonomous payload control project] was development of an autonomous payload control system on the basis of Motorola's powerful microprocessor family M 68,000." Id. According to Motorola, the M 68,000 microprocessor is a powerful semi-conductor, which is made by the U.S.-based company and is on the CoCom export control list. According to an ISRO annual report, both the ASLV and the PSLV Indian launch vehicle inertial guidance systems will employ an inertial guidance computer "based on the Motorola M 6800 microprocessor with 16-bit word length." Government of India, Department of Space, 1981-82 Annual Report, pp. 21-22. According to Motorola, however, the 6800 microprocessor has an 8-bit word length, not a 16-bit word length. Only the 68,000 series has a 16-bit word length. This suggests a typographical error in the Indian report.

The inertial guidance computer based on this microprocessor has already been tested by India: "An engineering model of the On Board Processor (OBP Mark-II) based on Motorola 6800 microprocessor has been integrated and exhaustive tests are being carried out. Interfacing and packaging details are being worked out." Government of India, Department of Space, 1982-83 Annual Report, p. 21. A rocket payload control system containing a DFVLR microprocessor and an ISRO interferometer was successfully tested in 1981. DFVLR Colloquium, id., at p. 27.

This program is still underway and is scheduled to end in 1989. Letter of May 1, 1989 from Dr. Dietmar Wurzel, DLR, to Gary Milhollin.